

An Electrically Heated Full Radiator.

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In a previous paper by the author* the value of the "radiation constant" of the Stefan-Boltzmann law was obtained, using an apparatus which fulfilled the condition of a full receiver; all previous determinations being open to objection on the ground that this condition was not attained. The "emitter" used in that investigation and maintained at a temperature of 1100° C. was of the usual type—a modified form of Heraeus furnace; but it was pointed out at the time that such a radiator is by no means a uniform temperature enclosure, and that the author intended to construct such an enclosure which would approximate more nearly to the ideal full radiator.

The value of the radiation constant is open to criticism until it has been determined with apparatus in which both "emitter" and "receiver" fulfil "black body" conditions.

The present paper describes an electrically heated high temperature full radiator, for which there is such a pressing need in full radiation measurements.

The Form of the Radiator.—The radiator consists of a bottle-shaped crucible of alumina with a cylindrical body 8 inches in diameter, and with conical ends and circular aperture B (fig. 1). The crucible was wound with platinum strip for electrical heating in a manner to be described later.

This form of radiator is preferable to the sphere, as it somewhat simplifies the difficulty of the electrical winding, although considerable difficulty was experienced in winding the conical ends. A further advantage consists in the fact that the region A, which will be "visible" from the receiver, loses less radiation to the cold aperture B than it would do were that surface parallel to B. This principle is utilised in the receiver previously described.

Method of Electrical Winding.—It was desired to attain a temperature of at least 1000 – 1100° C., and for this purpose platinum strip was used. Experiments seem to show that alumina is not the ideal material for the crucible, on account of the fact that in the earlier experiments the platinum winding invariably broke down on cooling after maintaining the radiator for some hours at 1000° C., and after switching off the heating current. It

* "A Determination of the Radiation Constant," 'Roy. Soc. Proc.,' A, vol. 88, p. 49 (1913).

appeared that the platinum adhered to the crucible, and on cooling the expansion of the alumina fractured the platinum strip. In view of this property of the clays at high temperatures it is probable that porcelain would be preferable.

It was desirable that the strip should be held in position in some manner,

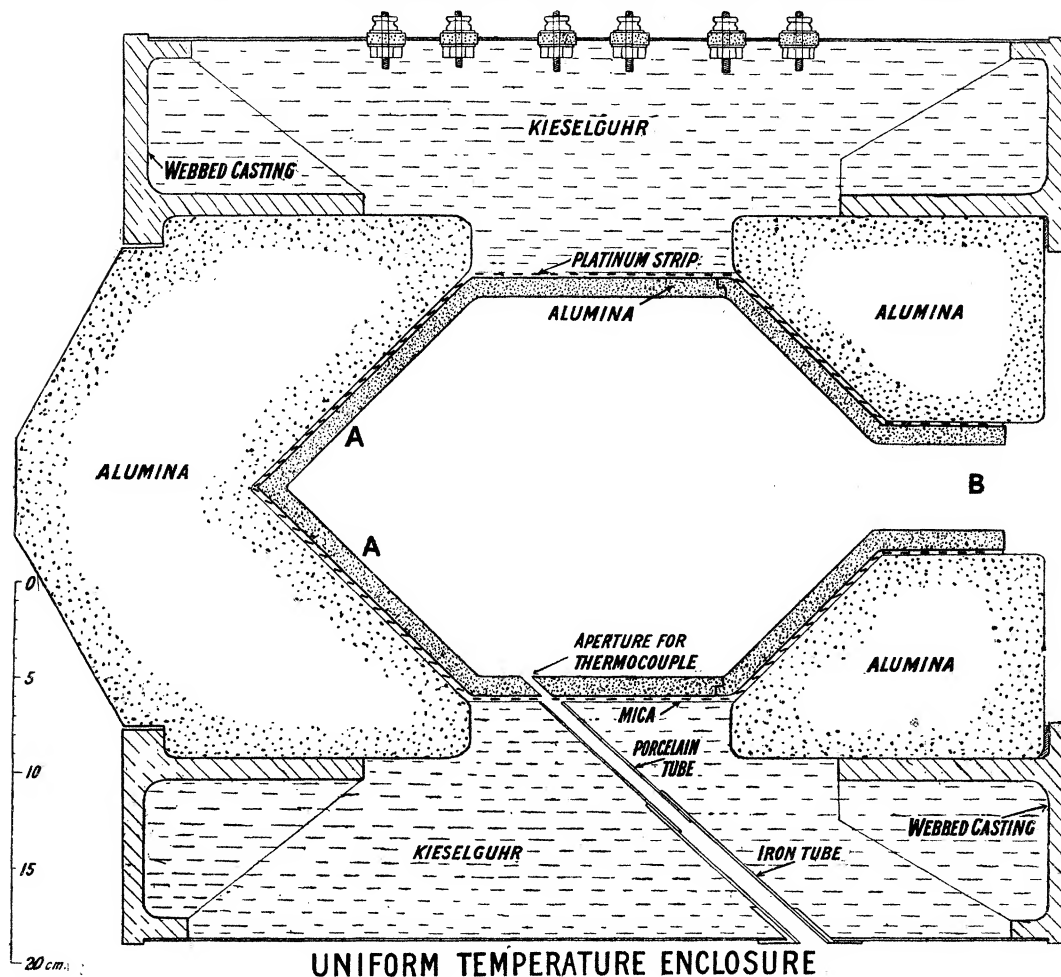


FIG. 1.

particularly on the cones. The dental cements tried for this purpose proved to be unsatisfactory—breakdowns continued to occur, and on examination the strip seemed to show that electrolysis was taking place with the cement. The two main difficulties to be overcome were (1) the expansion of the crucible on cooling, (2) electrolysis.

The first was solved by “crimping” the platinum strip between two cog-

wheels, and winding it so as to be separated from the crucible by a pliable mica bed. This prevented the strip adhering to the crucible and allowed of considerable movement. The electrolysis difficulty was overcome by removing all traces of dental cement and replacing it by pure aluminium oxide. Since the adoption of this method of winding no further difficulty has been experienced. These practical points are recorded as they may be of interest to others concerned in high temperature furnace work.

Some 30 metres of platinum strip 0.42 cm. wide and 0.012 cm. thick were used. This thickness was chosen for strength to minimise the risk of mechanical fracture. Before winding, the whole crucible was encased in mica to prevent the strip adhering to the alumina.

Winding the Cylinder.—The crimped platinum strip was wound over the mica jacket of the alumina cylinder with a spacing of approximately 1 cm. between the windings. The platinum was now interlaced with narrow mica strips to keep it in position and so prevent short-circuiting. This was covered with another mica jacket to prevent contact between the conductor and the kieselguhr. Although mica provides an excellent insulating medium which is chemically inactive, it becomes friable and powdery at 1000° C., and it was therefore necessary to provide an additional strengthening jacket which remains hard at high temperatures. This was attained by covering the whole with pure asbestos cloth and pasting the outside of this with asbestos cement. Fig. 2 shows the winding in section. On examination this was found to be in very good condition both mechanically and electrically after running on several occasions at 1100° C.

Winding the Cones.—Owing to the stiffness of the platinum strip it was impossible to make it lie flat on the conical surface. Further, some means had to be devised whereby the strip could be held in position during the process of winding and the spacing maintained during the heating so that there was no possibility of short-circuiting. The platinum strip was formed into a conical cage using stout mica strip as the spacing and supporting material. Equally spaced saw cuts were made in the mica, these served to grip the platinum and give the necessary spacing. The principle of the arrangement is shown in fig. 3. Two platinum coils and a few of the mica strips are illustrated on an enlarged scale. A strengthening matrix was provided by pouring into the interspaces a thick paste of pure aluminium oxide and water. The water was driven off by heating electrically, leaving a compact mass giving excellent insulation and support.

The ends of the platinum winding were brought out through the kieselguhr and connected to a row of six binding screws on the outside of the case. For the purpose of economy, heavy copper leads were used; but, owing to oxidation

of the copper-platinum joint at this high temperature, the copper had to be discarded. To avoid further difficulty, the platinum strip was made continuous to the binding screws, so that the only "contact" in the circuit was cool and visible.

Supporting and Lagging the Crucible.—The crucible was supported by means of two blocks of alumina which rested in the collars of the two circular end castings, as shown in fig. 1. These castings were rigidly attached to each other by means of a steel cylindrical jacket, the intervening spaces being filled with kieselguhr. The apparatus rested on a V-block casting and weighed approximately 130 kgm. A covered "hand-hole" was cut in the steel cylinder to facilitate the removal of moisture when drying out and also the examination of the interior when necessary.

Arrangements for Temperature Measurement.—Owing to the possible incon-

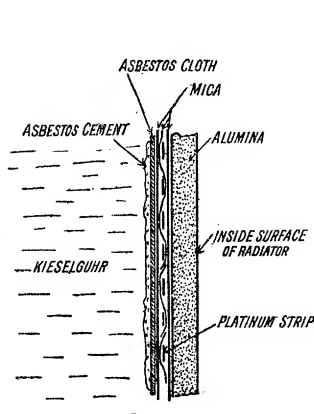


FIG. 2.

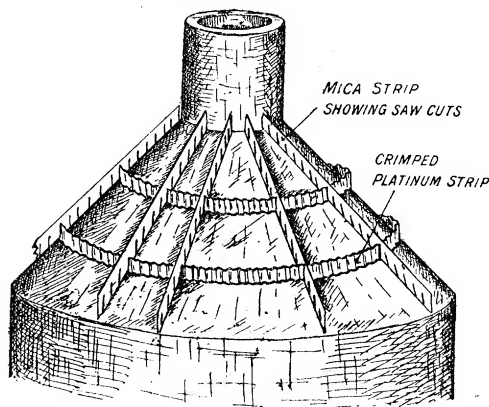


FIG. 3.

venience in introducing a thermocouple through the aperture B (fig. 1) during radiation measurements, a side hole was provided as shown. The direction of this inlet allowed of the couple being moved parallel to the radiating surface and any differences of temperature determined. Further, the position of the hole is such that it will not be "visible" from the aperture of the receiving apparatus to be used in future experiments.

The temperature was measured by a platinum platinum-rhodium thermocouple which had been calibrated at the National Physical Laboratory for the earlier experiments on the radiation constant. The temperature was observed by means of the deflection of a calibrated moving-coil galvanometer. This method is of sufficient accuracy for the present purpose of obtaining uniformity, since an absolute value of the temperature is not required.

In order to determine whether the galvanometer was indicating temperatures of the right order, a modification of the "hot-wire" method was used to check the indications of the thermocouple. While the furnace was slowly heating up, an additional couple of nickel-nichrome, joined by a short silver wire, was inserted and connected to a galvanometer, which served to indicate the time at which the silver melted. At this instant the scale reading of the Pt-PtRh couple was observed and was found to agree with the melting point of silver (961°C.) to within a few degrees.

Adjustment of the Heating Current to give a Uniform Temperature.—

Let the winding on the back cone A = Circuit 1.

„ „ cylinder = Circuit 2.

„ „ front cone = Circuit 3.

The resistances of the three circuits were measured at room temperature. Since the heat insulation of each of the three sections is not equally efficient, then it is obvious that an equal consumption of energy in each circuit will not provide a uniform temperature within the enclosure. The simplest plan is to allow each winding to act as its own thermometer by arranging that the increase in resistance is in the same ratio in each case. Usually the three circuits were put in series and a suitable current left running overnight. When the temperature reached $700\text{--}800^{\circ}\text{C.}$ the circuits were arranged in parallel, so that the energy consumption of each could be controlled and measured from time to time. At 1100°C. , the temperature at which uniformity was required, the energy consumed in each circuit was measured and then so adjusted that the resistance of each coil had increased in the same ratio. As will be seen later, this gave the required conditions. The following is characteristic of a set of observations:—

Let C_1V_1 , C_2V_2 , C_3V_3 , represent the current and potential for circuits 1, 2, and 3 respectively.

		$\frac{\text{Resist. at } 1100^{\circ}\text{C.}}{\text{Resist. at } 12^{\circ}\text{C.}}$	Energy consumption in watts.	Total energy consumption.
Circuit 1	$\left\{ \begin{array}{l} C_1 = 9.0 \text{ amps.} \\ V_1 = 70.0 \text{ volts} \end{array} \right\}$	4.2(0)	630	} 1743 watts
Circuit 2	$\left\{ \begin{array}{l} C_2 = 6.9 \text{ amps.} \\ V_2 = 67.9 \text{ volts} \end{array} \right\}$	4.2(0)	468	
Circuit 3	$\left\{ \begin{array}{l} C_3 = 8.7 \text{ amps.} \\ V_3 = 74.0 \text{ volts.} \end{array} \right\}$	4.2(0)	645	

Temperature = 1150°C.

Assuming the previously determined value of the radiation constant $= 5.89 \times 10^{-5}$ ergs/sec. cm.² deg.⁴, the rate of emission of energy through the aperture B at 1100° C.

$$= 508 \text{ watts.}$$

$$\begin{aligned} \text{"Efficiency"} &= \frac{\text{Energy appearing as radiation from aperture}}{\text{Total energy consumption}} = \frac{508}{1743} \\ &= 0.29, \end{aligned}$$

that is to say 29 per cent. of the energy put in appears as radiation. Making a similar calculation for the Heraeus furnace used in the earlier experiments and assuming that it emits full radiation it can be shown that the "efficiency" in this case is only about 25 per cent.

Note.—The energy was supplied by a direct current machine capable of giving 50 amperes at any potential from 20 to 160 volts. By this means the potential could be varied and the necessity for resistances variable over large ranges avoided. One small variable resistance in each circuit was provided and adjusted such that the machine was running at 110 volts when the temperature required was obtained. To avoid fluctuations in the dynamo potential the machine was now switched in parallel with the departmental 110 volt battery. When perfectly steady conditions of temperature were desired the machine was thrown out of circuit, leaving the radiator running off the battery alone. The electrical connections are shown in fig. 4.

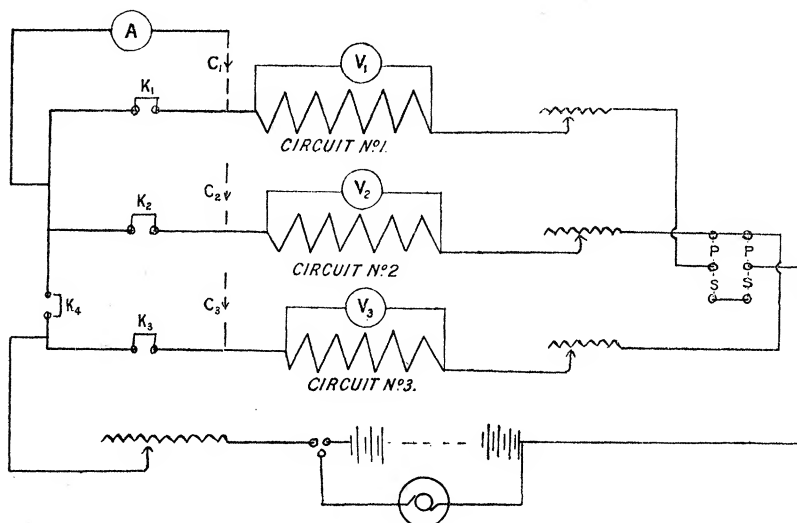


FIG. 4.—Electrical connections for constant-temperature enclosure. For "parallel" close PP and K₄. For "series" close SS and open K₄.

Exploration of Temperature Distribution.—This was most conveniently carried out by inserting the thermocouple through the aperture B. In order to place the junction at different points within the radiator the length of the couple immersed must vary if used in the ordinary way. Unless the wires of the couple are chemically pure and physically uniform the electromotive force will depend upon the length immersed. It was known from previous investigation that the couple used was defective in this respect. It was therefore necessary to devise some means of reaching different parts of the radiator, keeping the length of the couple immersed constant. The couple was insulated by means of twin-bore fireclay tubing which was supported in a porcelain tube so that the break K in the twin fireclay (see fig. 5) was

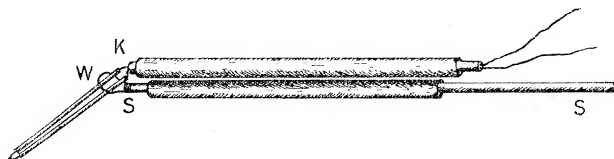


FIG. 5.

approximately at the centre of the enclosure. Another porcelain tube was attached alongside and carried a loosely fitting fused silica tube provided with a platinum wire loop W. This loop encircled the loose end of the thermocouple so that the junction could be brought to any position within the enclosure by sliding the silica tube S in its porcelain guide. In this manner the temperature distribution was determined. For the values of the energy consumption given above the temperatures at the various points were as follows:—

A series of observations of the temperature at the various positions shown in fig. 6 were taken in the following order:—

Position of junction.	Temperature.	Position of junction.	Temperature.
(2)	1150° C.	(5)	1154° C.
(1)	1151	(3)	1155
(3)	1153	(1)	1154

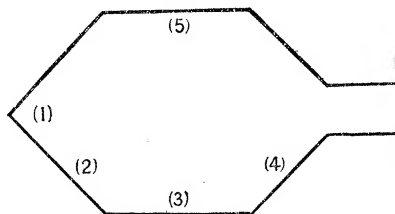


FIG. 6.—Vertical Section of Radiator.

It will be seen that the temperature was rising.

After waiting for steadier conditions the following series were taken :—

Position of junction.	Temperature.	Position of junction.	Temperature.
(3)	1149° C.	(3)	1150° C.
(4)	1147	(1)	1149
(1)	1149	(4)	1150

There is evidence here of a slight rise of temperature and the maximum difference of 3° C. occurs at the same place (position 4). It is quite useless to attempt further refinements at the present stage, since it is intended to determine the radiation constant for various temperature distributions within the enclosure. The results so obtained will determine the degree of uniformity which is necessary. If for instance the temperature of the cone opposite A is reduced by 100° C. and the value of the radiation constant obtained remained unaltered then the uniformity described above is sufficiently good. For this reason it is proposed to proceed with the radiation experiment without further delay.

The Quality of the Radiation emitted.—There is no satisfactory means of determining the diffusing power of a sample of the alumina at the temperature of the radiator (1100° C.), owing to the difficulty of obtaining the actual temperature of the radiating surface of an exposed sample. It is highly probable that a porous clay is an exceedingly good radiator on account of the pores providing a surface of minute full radiators. Such was the surface of the crucible. As a further precaution this surface was covered with a dull black coating (by Messrs. Morgan, of Battersea, London, S.W.) which would withstand 1100° C.

My colleague, Dr. Guy Barlow, has shown that the radiation passing through a circular aperture of area a in a spherical uniform temperature cavity of cross-section A departs from the full radiation at that temperature by approximately aR/A per cent., where R is the percentage of the radiation diffusely reflected by the material.

If we assume that the black alumina surface diffusely reflects as much as 5 per cent., then the radiation from the aperture B departs from the full radiation at that temperature by only about 0·2 per cent.

I am indebted to the late Prof. J. H. Poynting, F.R.S., for granting the funds which enabled me to carry out this investigation, and also to Mr. G. O. Harrison, of the Physics Workshop, for the valuable assistance he has rendered.